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GB 107460
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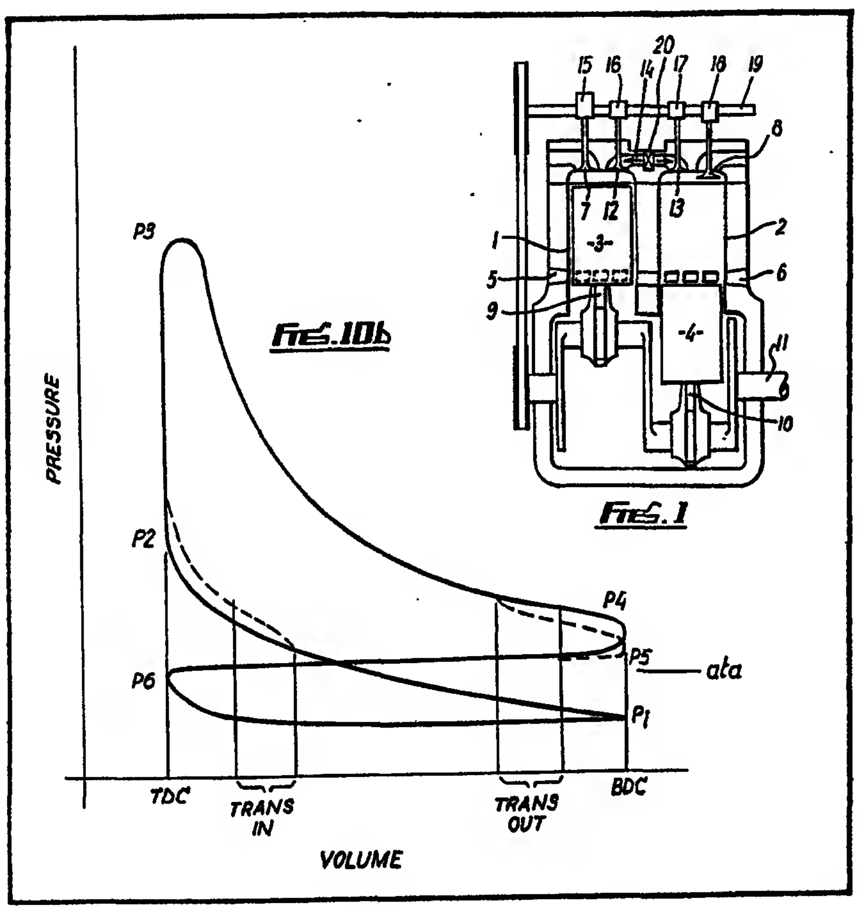
(71) Applicant
Rolls-Royce Motors Limited, Pym's Lane, Crewe, CW1 3PL, Cheshire
(72) Inventor
John Marshall Read
(74) Agent
Wilson, Gunn & Ellis

(54) Exhaust Gas Recirculation in an Internal Combustion Engine

(57) A multicylinder internal combustion engine comprises a transfer duct 14 connecting two cylinders 1 and 2 and transfer valves 12 and 13 operative to open and close the duct to allow some exhaust gas to transfer from one cylinder to the other to preheat the charge in that cylinder near the end (P_1) of that cylinder compression stroke (P_1 to P_2 Fig. 10*b*). Transfer takes place before the exhaust valve 7, 8 in the said one cylinder has opened (P_4) and if desired opening of the exhaust valve may be delayed. The duct may be defined within or external to the cylinder block and is as short as possible and the transfer valves may be cam operated from a camshaft 19 driven from the camshaft 11.



The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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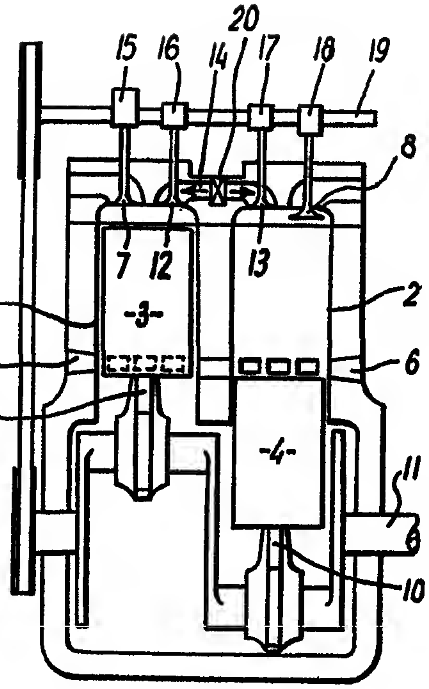

FIG. 1

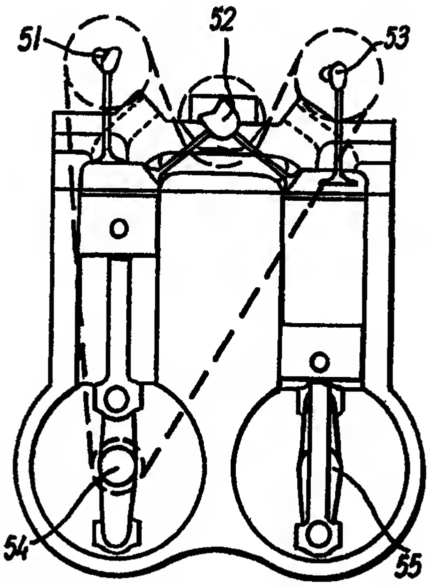

FIG. 2

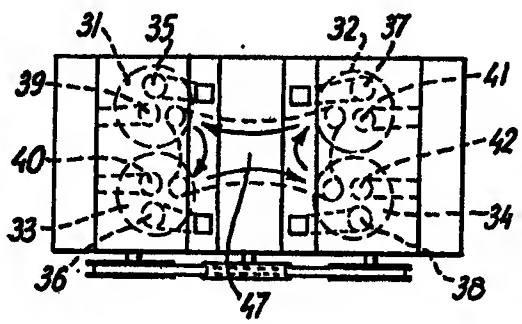

FIG. 3

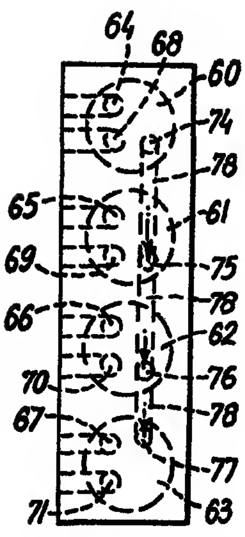

FIG. 5

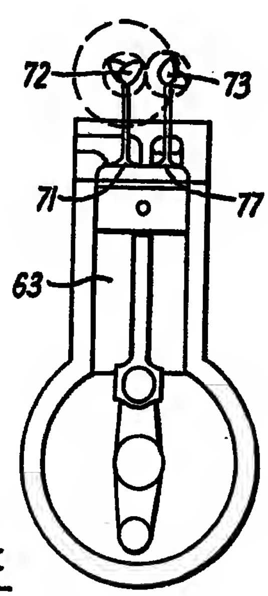

FIG. 4

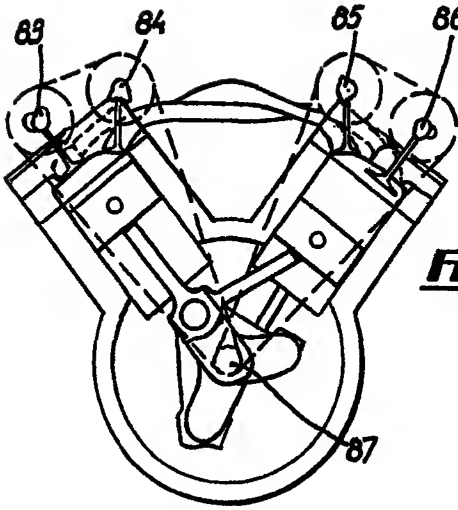

FIG. 6

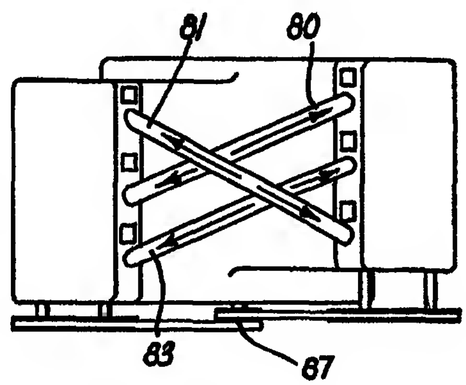

FIG. 7

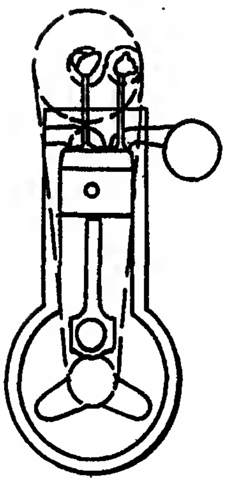

FIG. 8

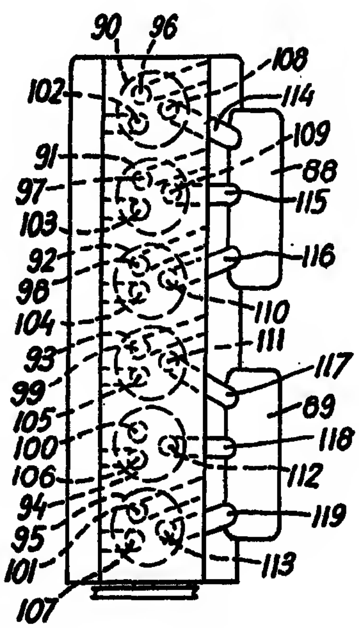

FIG. 9

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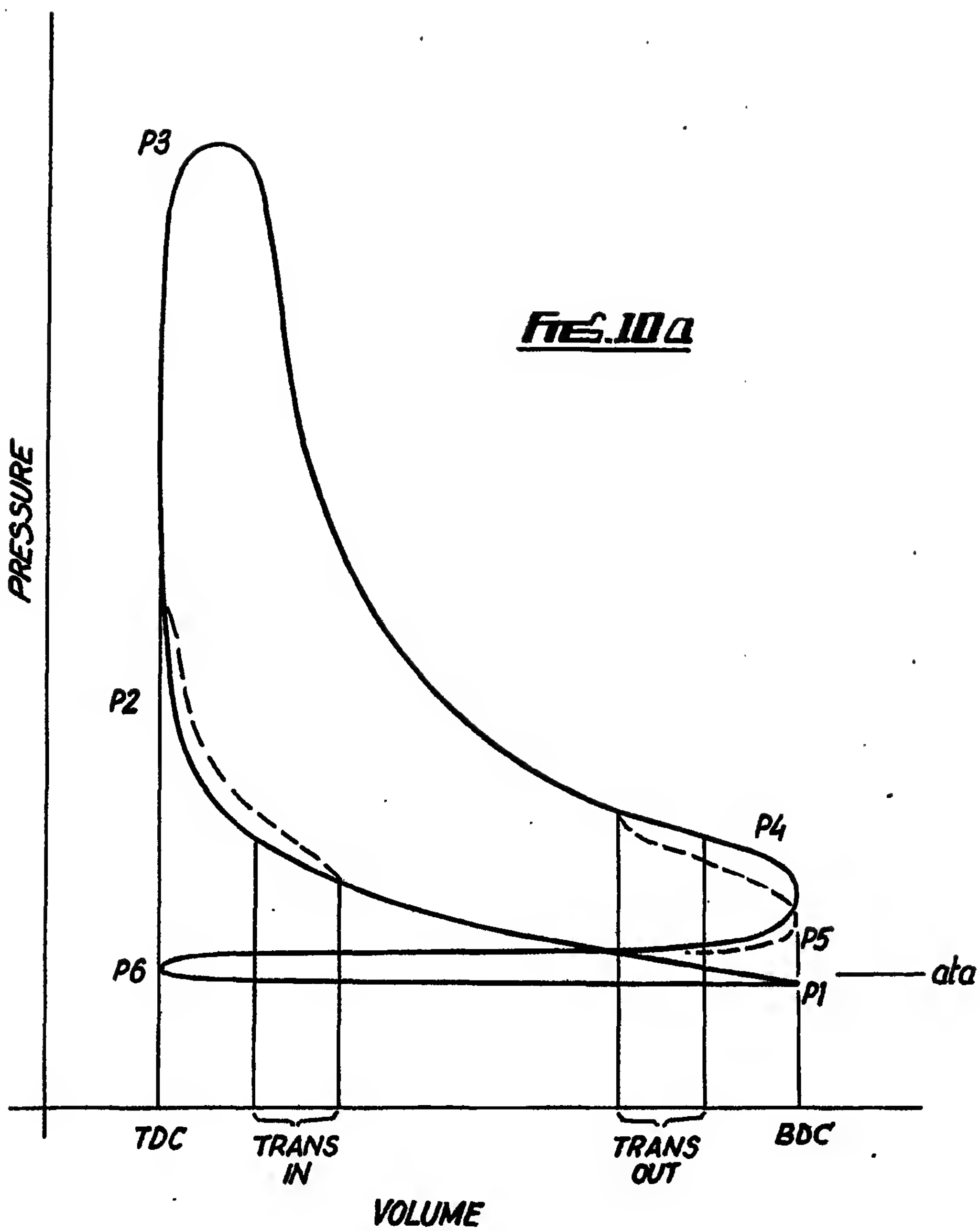

FIG. 10 a

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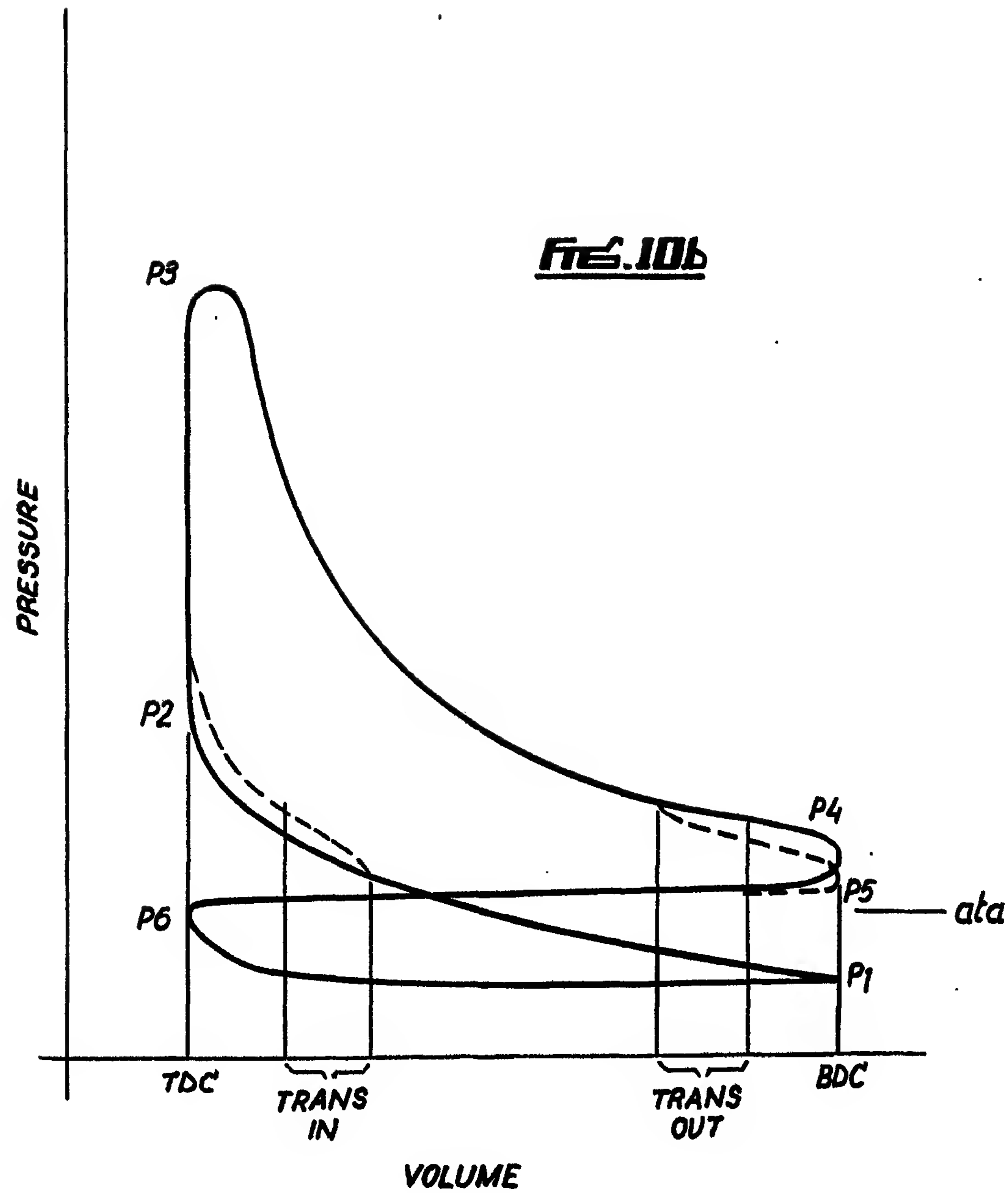
FIG. 10b



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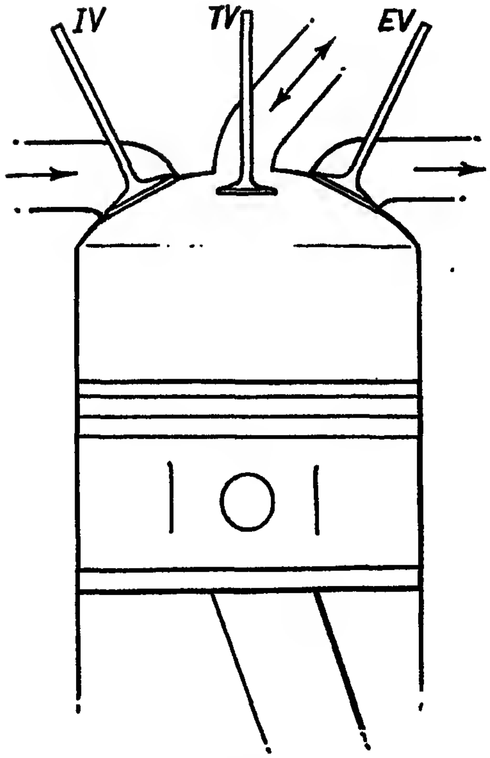

FIG. 11a

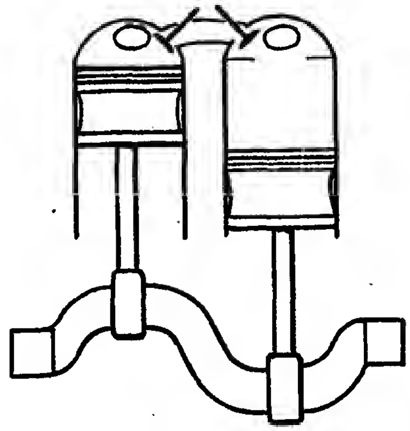

FIG. 11b

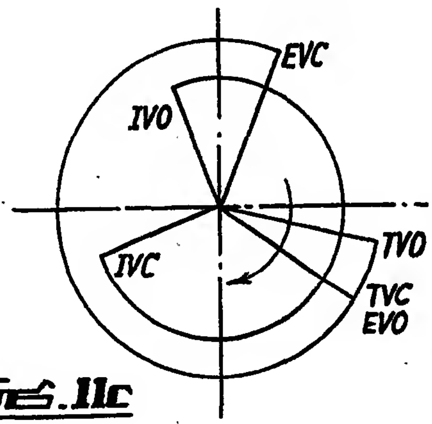

FIG. 11c

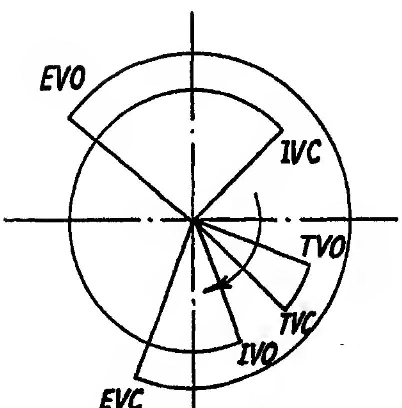

FIG. 11d

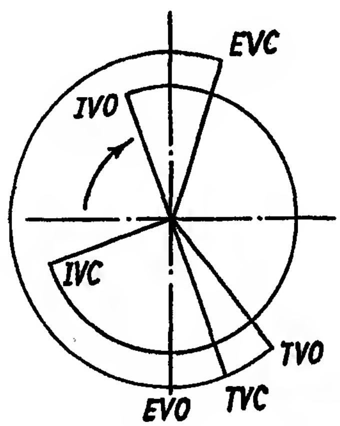

FIG. 11e

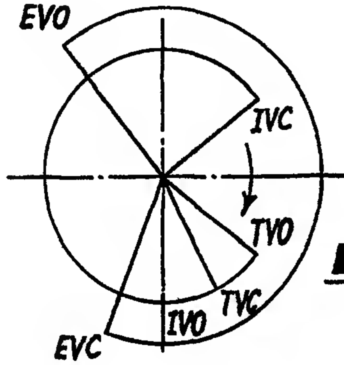

FIG. 11f

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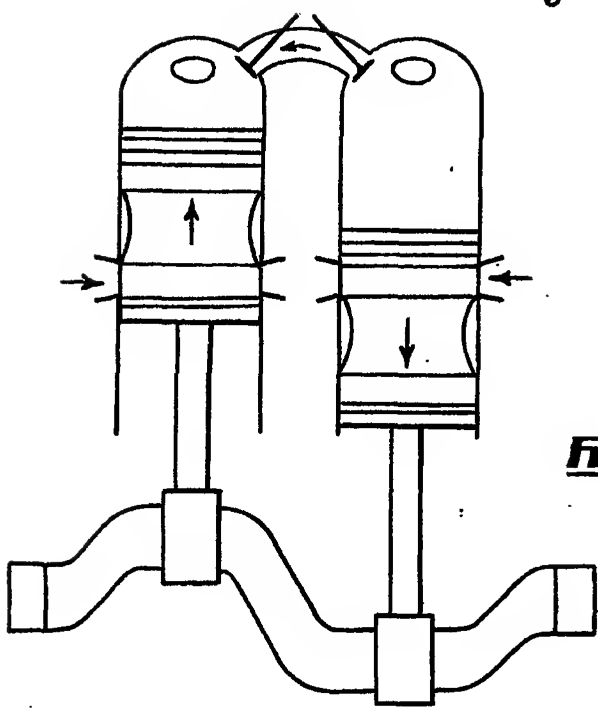

FIG. 12a

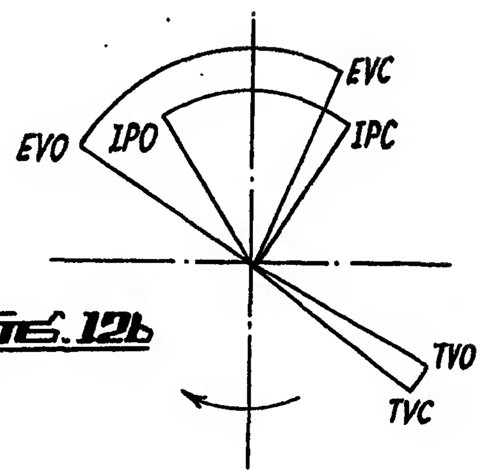

FIG. 12b

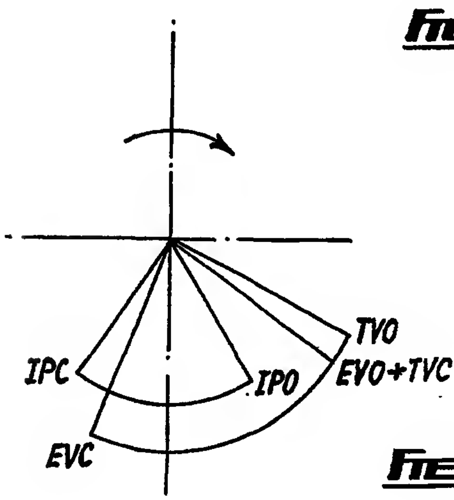

FIG. 12c

SPECIFICATION
An Internal Combustion Engine

The present conventional internal combustion engine whether designed to operate on the compression ignition diesel or premixed charge or stratified charge prinicple is inefficient in that a considerable proportion of the heat content of the fual is unused and is carried away in the exhaust gases. Certain devices such as exhaust turbines and turbochargers have been devaloped in an effort to recuperate some of this waste. However, thesa devices are not ideal in that they involve separate machinery, their installation is often cumbersome and their characteristics in the absence of yet further special control systems seldom readily suit tha internal combustion engine.

Additionally there is presently a need on many engines to provide a means of recirculating a proportion of the exhaust products to be includad with the fresh cylinder charga as a means of reducing the genaration of oxides of nitrogen in the cylinder which occurs during the high temperature phase of combustion. Present devices achieve this by introducing a proportion of exhaust products into the induction system to be inhaled with the fresh charge with the result that the weight of fresh charge is reduced with a corresponding reduction in engine power.

The present invention seeks to offar an improvement in the thermal efficiency of the internal combustion engine itself by re-employing a certain proportion of the waste heat in the exhaust to preheat the charge in the cylinder at the end of compression so that a proportionate reduction in the amount of fuel required to be added can be made for the same work output: in other words the specific fuel consumption is reduced. Further by introducing the exhaust gas at or near the and of the compression stroke rather than during the induction stroke there is no displacemant of fresh charge.

According to one aspect of the presant invention, there is provided an internal combustion engine comprising a cylinder a piston disposed in the cylinder an inlet laading into the cylinder, an exhaust leading from the cylinder, a transfer valve leading into tha cylinder and control means operative to open the transfer valve near the end of the compression stroke to allow a preheated gas charge to be forced into the cylinder.

An advantageous ambodiment of the invention may comprise any one or more of tha following preferred features:—

(a) The internal combustion engine is a multicylinder engina and a transfer valve allows the exhaust products from one cylinder to be fed to another.

(b) The internal combustion engine is a two-cylinder two-stroke engine.

(c) The internal combustion engine is a four-cylinder four-stroke engine.

(d) The internal combustion engine is a six-cylinder four-stroke engine.

(e) The internal combustion engine is an eight-cylinder four-stroke engine.

(f) The piston of tha cylindar of the engine of (a) from which exhaust gas products are taken is 180° out of phase with the pistion of the cylinder to which tha axhaust gas products are transferred.

(g) In the internal combustion engine of (a) the transfar valve is disposed at one and of a transfer duct joining the two cylinders.

(h) The duct langth of the duct of (g) is as short as possible.

(i) The flame trap is disposed in the transfer duct of (g) or (h).

(j) The control means comprises a cam operative to open the transfar valve shortly before the opaning of the exhaust.

(k) The cam of (j) is supported on a camshaft and means are provided for driving the camshaft at the same speed as the crankshaft of the engine.

According to another aspect of the present invention, thara is provided a multicylinder internal combustion engine in which each cylinder comprises an exhaust, and inlet and a transfer valve, the transfer valve being disposed in a transfer duct connecting the cylinder to the or another cylindar and in which control means are providad operative to open the or each transfer valve to allow exhaust gases from one cylinder connected to the duct to be transferred to the other cylinder connected to the duct near the end of the compression stroke of the other cylinder.

The invention also comprises a method of operating a multicylinder engine in which part of tha combustion products of one cylinder are transferred to another cylinder shortly before top daad centre of the piston in that other cylinder. To this end the transfer valves in the transfer duct connacting the two cylinders are advantageously simultaneously opened shortly before the opening of tha normal exhaust valve or port. This latter opening may be delayed if necessary. In this way, exhaust gases from the first cylinder are driven by the residual overpressure in that cylinder into the second cylindar near the end of its compression stroke.

In order that the invention may be more clearly understood, several embodiments of the invention will now be describad, by way of example, with reference to the accompanying drawings, in which:—

Figure 1 shows a two cylinder two stroke internal combustion engine,

Figure 2 shows an end elevational view of a four cylinder four stroke internal combustion engine,

Figure 3 shows a plan view of the engine shown in Figure 2,

Figure 4 shows an end elevational view of another form of four cylinder four stroke internal combustion angine,

Figure 5 shows a plan view of the engine shown in Figure 4,

Figure 6 shows an end elevational view of a V-six four stroke engine

Figure 7 is a diagrammatic plan view of the engine shown in Figure 6,

Figure 8 shows an end elevational view of an in line six cylinder four-stroke engine,

Figure 9 is a diagrammatic plan viaw of the engine shown In Figure 8,

Figures 10*a* and 10*b* are graphs of the pressure/volume relationship for a four-stroke angine at full and part throttla respectively,

Figures 11*a* to 11*e* raspactively show practical valve avent timing for a four-stroka angine, and

Figures 12*a* to 12*c* raspactively show practical valve evant timings for a two-stroke angina.

Figure 1 Illustratas a uniflow two-stroka angine in which a proportion of the exhaust charge can be transferred directly batwaen cylinders which are 180° out of phase. The two cylinders are refarenced 1 and 2 respectively corresponding pistons 3 and 4, inlats 5 and 6, and exhaust valvas 7 and 8. The pistons 3 and 4 are mounted *via* con rods 9 and 10 on a crankshaft 11 in the usual way. Two further transfar valves 12 and 13 are disposed in respectiva cylindars 1 and 2 and at opposite ends respectively of a transfar duct 14. Tha exhaust and transfar valvas are oparatad by cams 15 to 18 supportad on a cam shaft 19 toothed belt driven from the crankshaft 11. The gas transfar passage 14 between tha cylinders is direct and of low voluma, and the charge can readily retain its heat. The camshaft 19 runs at crankshaft spaed and amploys a conventional cam profile. A flame trap 20 is disposed in tha transfar ducts to prevent the occurrence of uncontrolled ignition.

Figures 2 and 3 illustrate a four cylindar four-stroke intamal combustion angina with tha cylindars 31 to 34 in squara form. Each cylinder includes an Inlet valve 35 to 38, an axhaust valve 39 to 42 and a transfar valve 43 to 46. A common plenum chamber 47 connacts the transfer valves togather as shown In Figure 3 and arrows indicate the flow of axhaust gases during oparation of the engine. The valves are opened and closed by cams supportad on threa overhaad camshafts 51 to 53 toothad belt driven from one of two crankshafts 54 and 55. The square four layout allows direct transfar of the charga. The path for the gasas is short, and could be raduced furthar by inclination of tha cylinder axas if raquired.

Figures 4 and 5 respectivaly illustrata side elevational and plan views of a four cylinder In line four-stroke angine. Tha cylindars are respectively referenced 60 to 63, inlet valves 64 to 67, exhaust valves 68 to 71, cam-shafts 72 and 73 and transfar valves 74 to 77. The transfer valvas are connactad as shown by transfar ducts 78 which are all in lina. Hara again the axhaust gas transfer is direct although this arrangement may not ba so satisfactory as the squara arrangement of tha angine of Figuras 2 and 3 as the disproportion in tha path lengths batwaen the outer cylindars 60 and 63 and the inner and adjacent cylinders 61 and 62 could cause problems of uneven distribution of the transferred charge.

Direct transfer can also be employed in a V six four-stroke engina. A sida elevational and plan view of such an angine are shown in Figuras 6 and 7 respectively. The timing of tha transfer phase will dictate the angle of tha V. Frea choice of V angle is available if a rasarvior is employad, but soma loss of afficiency is to ba expactad from the Increased volume and surfaca araa. In Figure 7 the transfar ducts ara raferanced 80 to 82 and tha direction of exhaust gas flows by arrows. Ovarhead cams or camshafts 83 to 86 drivan from the camshaft 87 open and close the various Inlet exhaust and transfar valvas.

In the abova described four-stroke anglnas of Figures 2 to 7, the cam operating the transfer valves Illustratad has two lobes spaced 90° apart. The camshaft runs at half crankshaft speed. The relation batween camshaft and crankshaft speeds is dependent on the loba spacing of tha cams and any satisfactory permutation of thesa threa factors may ba used.

Other four-stroka angine layouts, viz: in lina six cylindar, flat six, V eight, requira a gas resarvoir to be employed. Employment of such a raservoir gives freedom to vary tha timing of tha transfer phase unaffactad by and without restricting the cylinder configuration. In tha in lina six cylindar engine illustrated in Figures 8 and 9 two separate chambars 88 and 89 are used to kaep transfar volumes low and path lengths to a minimum. The six cylinders are referenced 90 to 95, Inlat valves 96 to 101, exhaust valves 102 to 107 and transfar valvas 108 to 113. Tha thraa transfer valvas 108 to 110 lead *via* respective transfer ducts 114 to 116 to chambar 88 and tha threa transfar valves 111 to 113 *via* raspective transfer ducts 117 to 119 to the chambar 89. Such chambers are preferably insulated to minimisa heat loss, and passages in general are uncooled.

Figures 10*a* and 10*b* illustrata the pressure/volume diagrams typical of a four-stroke engine unthrottlad, and at part throttle whare a throttle is amployad, and indicata tha araas of gas transfer. The induction part of tha cycla is rapresentad batwean P6 and P1, compression batwaen P1 and P2, combustion between P2 and P3, expansion between P3 and P4, exhaust blowdown betwaen P4 and P5, and exhaust pumping batwaan P5 and P6. The transfer periods to and from tha cylinder are shown, togethar with the modifications to the pressure/voluma diagram that result (shown dotted).

Figure 11*a* diagrammatically shows tha threa valve arrangamant of ona cylinder, Figure 11*b* tha out of phasa arrangement of two adjacant cylindars and Figures 11*c* to 11*f* tha points at which the various valves open for different angine conditions in the course of an angine cycla. In both Figura 11 and 12 the lattar referencas indicate tha following:

IV Inlat valva

EV Exhaust valve

TV Transfer velve
IVO Inlet valve open
IVC Inlet vawvclosed
IPO Inlet port open
IPC Inlet port closed
EVO Exhaust valve open
EVC Exhaust valve closed
TVO Trasnsfer valve open
TVC Transfer valve closed

Thus in the above described engines, e proportion of the heet energy conteining exhaust gases from the first cylinder are driven by the residuel overpressure in that cylinder into the second cylinder near the end of its compression stroke and shortly before the injection of fuel, or the occurrence of the spark in a premixed charge engine, to provide both preheating of the charge to the benefit of thermal efficiency end exheust gas re-circulation to the benefit of exhaust emissions. Additionelly by the location, direction and shaping of the above extra valve port or gas transfer means it is possible to influence the movement and distribution of the trapped charge at and around piston top dead centre position to influence combustion and charge stratificetion if required. In Figures 11b and 12*a* the first cylinder is the left-hand cylinder and the second cylinder is the right-hand cylinder. Figures 11d, 11f end 12b relate to the first cylinder and Figures 11e, 11c and 12c relate to the second cylinder.

In e practicel design of such e system the transfer port meens should be sufficiently direct as to avoid undue losses due to duct length or volume, and this has to be considered in the cylinder leyout of the engine.

Also in the case of the premixed charge engine the amount of charge preheeting cannot be unlimited or detonation of the charge will occur.

Figure 12*a* represents the 180° out of phese arrangement of two adjacent cylinders of a two-stroke engine and figures 12*b* and 12*c* the position et which the verious valves open and close in the course of a cycle.

It will be appreciated that the above embodiments heve been described by wey of example only and that many variations are possible without departing from the scope of the invention. In perticular, any suiteble cylinder arrangement may be used. For exemple, in eddition to those described a parellel twin, eight cylinder in-line, V8 or flat 4 may equally well be used.

Although in the above described examples, the velves ere opened by overheed cams supported by toothed-belt driven overhead cemshafts any suiteble valve disposition and method of valve opening may be used.

The transfer pessage between cylinders may be internal or external to the engine block. If internal, it should edventegeously be uncooled. An external passage mey be formed of a suitable material and disposed across the top of the engine block. Having an internal pessage obviates any seeling problems as the passage is defined by the material of the block itself.

Under some circumstances, it mey be advantageous to control the opening of the trensfer valves in dependence upon an operating characteristic of the engine such as engine speed or load. Such control may be mechanical or electronic as desired.

Also under some circumstances it mey be advantageous to employ e throttle valve in the transfer passage to limit the mess of gas transfer in dependence upon an operating cherecteristic of the engine such es engine speed or load. Control of such throttle velve may be mechenical or electronic as desired. The throttle valve mey be placed in a position similar to thet of the flame trap 20 shown in Figure 1.

Cleims

1. An internal combustion engine comprising a cylinder, a piston disposed in the cylinder, an inlet leading into the cylinder, an exhaust leading from the cylinder, a transfer valve leeding into the cylinder and control means operatiave to open the transfer valve naar the end of the compression stroke to allow a preheated ges charge to be forced into the cylinder.

2. An internal combustion engine as claimed in Claim 1, which is e multicylinder engine end in which the transfer velve ellows the exhaust products from one cylinder to be fed to another.

3. An internal combustion engine as claimed in Claim 1 or 2, which is a two-cylinder two-stroke engine.

4. An internal combustion engine as claimed in Claim 1 or 2, which is a four-cylinder four-stroke engine.

5. An internal combustion engine es claimed in Claim 1 or 2, which is a six-cylinder four-stroke engine.

6. An internal combustion engine as claimed in Claim 1 or 2, which is an eight-cylinder four-stroke engine.

7. An internel combustion engine es claimed in Claim 2, in which the piston of the cylinder of the engine from which exheust gas products are taken is 180° out of phase with the piston of the cylinder to which the exhaust ges products are transferred.

8. An internal combustion engine as claimed in Claim 2 or 7, in which the transfer velve is disposed et one end of a transfer duct joining the two cylinders.

9. An internal combustion engine as cleimed in Cleim 8, in which the duct length of the transfer duct is es short as possible.

10. An internal combustion engine as claimed in Claim 8 or 9, in which a fleme trap is disposed in the transfer duct.

11. An internal combustion engine as claimed in Cleim 2, or in eny of Cleims 3 to 10 when appendent to Claim 2, in which the control meens comprises a cam operative to open the transfer valve shortly before the opening of the exhaust of the said one cylinder.

12. An internal combustion engine as cleimed in Claim 11, in which the cam is supported on a

camshaft and means are provided for driving the camshaft at the same speed as the crankshaft of the engine.

13. A multicylinder internal combustion engine in which each cylinder comprises an exhaust, an inlet and a transfer valve, the transfer valve being disposed in a transfer duct connecting the cylinder to the or another cylinder and in which control means are provided operative to open the or each transfer valve to allow exhaust gases from one cylinder connected to the duct to be transferred to the other cylinder connected to the duct near the end of the compression stroke of the other cylinder.

14. A method of operating a multicylinder internal combustion engine in which part of the combustion products of one cylinder are transferred to another cylinder shortly before top dead centre of the piston in that other cylinder.

15. A method as claimed in Claim 1, in which the products of one cylinder are transferred to another cylinder through a transfer duct.

16. A method as claimed in Claim 15, in which the transfer through the transfer duct is governed by transfer valves which are opened simultaneously.

17. A method as claimed in Claim 16, in which the exhaust valve of the said one cylinder is opened after the opening of the transfer valves so that the residual overpressure in that cylinder drives the exhaust gas over into the other cylinder.

18. A method as claimed in Claim 17, in which the exhaust valve opening in the said one cylinder is delayed.

19. An internal combustion engine substantially as hereinbefore described with reference to Figures 1 and 12, or Figures 2, 3, 10 and 11 or Figures 4 and 5, or Figures 6 and 7, or Figures 8 and 9 of the accompanying drawings.

20. A method of operating a multicylinder engine substantially as hereinbefore described with reference to Figures 1 and 12, or Figures 2, 3, 10 and 11 or Figures 4 and 5, or Figures 6 and 7, or Figures 8 and 9 of the accompanying drawings.

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